

THE SOCIETY FOR WIND VIGILANCE

WIND TURBINE NOISE, SLEEP AND HEALTH

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Notes:

This paper is based on proofs of evidence produced for several UK Planning Inquiries. As such, it concentrates on the regulatory system in the UK. Other jurisdictions will have different systems.

The aim is to inform those seeking to regulate the siting of wind turbines close to human habitation.

It will be updated regularly as new information comes to hand.

Users are encouraged to check the Society for Wind Vigilance Website for the latest updates

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CD Hanning
April 2010

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Summary

Section 1 sets out the author's expertise in sleep medicine and physiology, the scope of the report and source material.

Section 2 reviews the basic physiology of sleep. Noise can disturb sleep by causing awakenings, which are remembered and arousals, which are not recalled but are more likely. Both disrupt sleep making it unrefreshing. Research on the effects of wind turbine noise has concentrated on remembered awakenings and has thus underestimated the effects.

Inadequate or poor quality sleep has many health consequences apart from daytime sleepiness and fatigue. These include obesity, poor memory, increased risk of diabetes, heart disease and high blood pressure. Vulnerable groups such as children and the elderly may be at greater risk.

Section 3 reviews research on wind turbine noise, sleep disturbance and health. These include the major contributions of van den Berg and Pedersen and the dose-response relationship derived from their data. Also considered are the Salford study and the Hayes McKenzie Partnership study commissioned by the DTI.

Recent major reports by WHO and RIVM are reviewed, both of which mandate lower night time noise levels than are permitted by ETSU-R-97. Predicted external turbine noise should not exceed 35dB to avoid disturbance to sleep and 40dB to avoid risks to health. Experience of existing wind farms mandates a setback of at least 1.5km in order to avoid disturbance to sleep.

It is concluded that there is compelling evidence that wind turbine noise can and does disturb sleep and impair the health of those living too close and that current guidance is inadequate protection.

Section 4 examines the mitigation of wind turbine noise. It is concluded that the occupants of properties sited within 1.5km of turbines will suffer unacceptable levels of sleep disturbance and potential risk to their health.

Section 5 presents the conclusions of the report.

Section 6 lists the documents cited in support of this paper.

Figure 1. Sound level and annoyance for different noise sources

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Table 1. Response to wind turbine noise outdoors or indoors

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1. Introduction

1.1 The author

1.1.1. My name is Dr Christopher Hanning, Honorary Consultant in Sleep Disorders Medicine to the University Hospitals of Leicester NHS Trust, based at Leicester General Hospital, having retired in September 2007 as Consultant in Sleep Disorders Medicine. In 1969, I obtained a First class Honours BSc in Physiology and, in 1972, qualified in medicine, MB, BS, MRCS, LRCP from St Bartholomew's Hospital Medical School. After initial training in anaesthesia, I became a Fellow of the Royal College of Anaesthetists by examination in 1976 and was awarded a doctorate from the University of Leicester in 1996. I was appointed Senior Lecturer in Anaesthesia and Honorary Consultant Anaesthetist to Leicester General Hospital in 1981. In 1996, I was appointed Consultant Anaesthetist with a special interest in Sleep Medicine to Leicester General Hospital and Honorary Senior Lecturer to the University of Leicester.

1.1.2. My interest in sleep and its disorders began nearly 30 years ago and has grown ever since. I founded and ran the Leicester Sleep Disorders Service, one of the longest standing and largest services in the country, until retirement. The University Hospitals of Leicester NHS Trust named the Sleep Laboratory after me as a mark of its esteem. I was a founder member and President of the British Sleep Society and its honorary secretary for four years and have written and lectured extensively on sleep and its disorders and continue to be involved in research. My expertise in this field has been accepted by the civil, criminal and family courts. I chair the Advisory panel of the SOMNIA study, a major project investigating sleep quality in the elderly, and sit on Advisory panels for several companies with interests in sleep medicine. I am an Associate Member of the General Medical Council, chairing Investigation Committee hearings and Registration Panels. In 2010, I was invited to join the Board of the Society for Wind Vigilance.

1.2. Scope of report.

1.2.1. This report centres on the effects of industrial wind turbine noise on sleep, and consequent effects on health as this is the particular area of expertise of the author.

1.3. Source material

1.3.1. A full list of the publications cited and other source material is given in Section 7 and are cited in the text. Material was obtained by searching the Web of Science database using the search terms "Noise", "Sleep" and "Wind turbine", internet searches using the same words and scrutiny of the reference lists of published articles and reviews. Where several articles come to the same conclusion, only the most recent may be cited, in the interests of brevity. As far as possible, articles published in peer reviewed journals are cited. However, it is inevitable that some of the material is available only on the internet reflecting the paucity of government sponsored research, particularly in the UK.

2. Background

2.1. Introduction

2.1.1. There can be no reasonable doubt that industrial wind turbines whether singly or in groups ("wind farms") generate sufficient noise to disturb the sleep and impair the health of those living nearby. Section 5.1.1 of the draft New Zealand standard on wind farm noise, 2009, states: *"Limits for wind farm noise are required to provide protection against sleep disturbance and maintain reasonable residential amenity."* Reports from many different locations and different countries have a common set of symptoms and have been documented by Frey and Hadden (2007). New cases are documented regularly on the Internet. The symptoms include sleep disturbance, fatigue, headaches, dizziness, nausea, changes in mood and inability to concentrate and have been named "wind turbine syndrome" by Dr Nina Pierpont (2006). The experiences of the Davis (2008) and Rashleigh (2008) families from Lincolnshire whose homes, were around 900m from wind turbines make salutary reading. The noise, sleep disturbance and ill health eventually drove them from their homes and, in the Davis' case, legal action. Similar stories have been reported from around the world, usually in anecdotal form but in considerable numbers.

2.2. Sleep, sleep physiology and the effects of noise

2.2.1. Sleep is a universal phenomenon. Every living organism contains, within its DNA, genes for a body clock which regulates an activity-inactivity cycle. In mammals, including humans, this is expressed as one or more sleep periods per 24 hours. Sleep was previously thought to be a period of withdrawal from the world designed to allow the body to recuperate and repair itself. However, modern research has shown that sleep is primarily by the brain and for the brain. The major purpose of sleep seems to be the proper laying down and storage of memories, hence the need for adequate

sleep in children to facilitate learning and the poor memory and cognitive function in adults with impaired sleep from whatever cause.

2.2.2. Inadequate sleep has been associated not just with fatigue, sleepiness and cognitive impairment but also with an increased risk of obesity, impaired glucose tolerance (risk of diabetes), high blood pressure, heart disease, cancer, depression and impaired immunity as shown by susceptibility to the common cold virus. Sleepy people have an increased risk of road traffic accidents. Sleepiness, as a symptom, has as much impact on health as epilepsy and arthritis. It is not insignificant.

2.2.3 Humans have two types of sleep, slow wave (SWS) and rapid eye movement (REM). SWS is the deep sleep which occurs early in the night while REM or dreaming sleep occurs mostly in the second half of the night. Sleep is arranged in a succession of cycles, each lasting about 90 minutes. We commonly wake between cycles, particularly between the second and third, third and fourth and fourth and fifth cycles. Awakenings are not remembered if they are less than 30 seconds in duration. As we age, awakenings become more likely and longer so we start to remember them.

2.2.4. Noise interferes with sleep in several ways. Firstly, it may be sufficiently audible and annoying to prevent the onset of sleep or the return to sleep following an awakening. It is clear also that some types of noise are more annoying than others. Constant noise is less annoying than irregular noise which varies in frequency and loudness, for example, snoring, particularly if accompanied by the snorts of sleep apnoea (breath holding). The swishing or thumping impulsive noise associated with wind turbines seems to be particularly annoying as the frequency and loudness varies with changes in wind speed and local atmospheric conditions and the character of the noise may be perceived as threatening. While there is no doubt of the occurrence of these noises and their audibility over long distances, up to 3-4km in some reports, the actual cause has not yet been fully elucidated (Bowdler 2008). Despite recommendations by the Government's own Noise Working Group, government sponsored research in this area has been stopped. Stigwood

(2008), an independent noise consultant, has demonstrated that this noise pattern is common with large turbines.

2.2.5. Secondly, noise experienced during sleep may arouse or awaken the sleeper. A sufficiently loud or prolonged noise will result in full awakening which may be long enough to recall. Short awakenings are not recalled as, during the transition from sleep to wakefulness, one of the last functions to recover is memory (strictly, the transfer of information from short term to long term memory). The reverse is true for the transition from wakefulness to sleep. Thus only awakenings of longer than 20-30 seconds are subsequently recalled. Research that relies on recalled awakenings alone may therefore underestimate the effect.

2.2.6. Noise insufficient to cause awakening may cause an arousal. An arousal is brief, often only a few seconds long, with the sleeper moving from a deep level of sleep to a lighter level and back to a deeper level. Because full wakefulness is not reached, the sleeper has no memory of the event but the sleep has been disrupted just as effectively as if wakefulness had occurred. It is possible for several hundred arousals to occur each night without the sufferer being able to recall any of them. The sleep, because it is broken, is unrefreshing resulting in sleepiness, fatigue, headaches and poor memory and concentration (Martin 1997), many of the symptoms of "wind turbine syndrome". Arousals are associated not just with an increase in brain activity but also with physiological changes, an increase in heart rate and blood pressure, which are thought to be responsible for the increase in cardiovascular risk. A clear relationship between high blood pressure and aircraft noise exposure has been shown by the HYENA consortium (Haralabidis 2008, Jarup 2008) and between traffic noise and high blood pressure for adults (Barregard 2009) and, worryingly, for preschool children (Belojevic 2008). The MESA study has suggested a link between exposure to traffic and alterations in heart function (Van, Hee 2009) and Selander and colleagues (2009) have suggested a link with myocardial infarction (heart attack) but neither could separate noise effects from pollution. Arousals occur naturally during sleep and increase with age (Boselli 1998), as do

awakenings which may make the elderly more vulnerable to wind turbine noise. Arousals may be caused by sound events as low as 32 dB(A) and awakenings with events of 42dB(A) (Muzet and Miedema 2005). Arousals in SWS may trigger a parasomnia (sleep walking, night terrors etc.). Pierpont (2009) notes that parasomnias developed in some of the children exposed to turbine noise in her study group.

2.2.7. Arousals are caused by aircraft, railway and traffic noise. In one study of aircraft noise, arousals were four times more likely to result than awakenings (Basner 2008a) and resulted in daytime sleepiness (Basner 2008b). Freight trains are more likely to cause arousals than passenger trains, presumably because they are slower, generating more low frequency noise and taking longer to pass (Saremi 2008). The noise of wind turbines has been likened to a "passing train that never passes" which may explain why wind turbine noise is prone to cause sleep disruption. A recent study of over 18000 subjects has shown a link between exposure to traffic noise and "the risk of getting up tired and not rested in the morning (de Kluizenaar, 2009). This study, together with that of Basner (2008b) confirms that excessive noise disturbs sleep sufficiently to impair its restorative properties and adds credence to the anecdotal reports of those living near wind turbines.

2.2.8. Studies of different alarm signals have shown that arousals and awakenings occur at lower sound levels with low frequency sounds than those of higher frequency (Bruck 2009). Repeated short beeps of 400-520Hz were most intrusive, leading to arousal and awakening. Wind turbine noise often has a considerable low frequency component and has an impulsive nature which may, in part, explain its adverse effect on sleep.

2.2.9. It is often claimed on the basis of anecdotal evidence that continual exposure to a noise results in habituation, i.e. one gets used to the noise. There is no research to confirm this assertion although it has been suggested that the absence of noise for those usually subjected to high levels may cause insomnia (HPA 2009 5.29). A recent small study (Pirrera

et al. 2009) looking at the effects of traffic noise on sleep efficiency suggests that habituation does not occur. Griefahn and colleagues (2008) have shown that the increases in heart rate with traffic noise induced arousals show no habituation.

2.2.10. Sleep disturbance and impairment of the ability to return to sleep is not trivial as almost all of us can testify. In the short term, the resulting deprivation of sleep results in daytime fatigue and sleepiness, poor concentration and memory function. Accident risks increase. In the longer term, sleep deprivation is linked to depression, weight gain, diabetes, high blood pressure and heart disease. There is a very large body of literature but please see Meerlo et al., 2008 for recent work on this subject as well as the 2009 WHO/EU Night Noise Guidelines for Europe and the recent reports of the Health Protection Agency (HPA 2009) and DEFRA (Berry and Flindell, 2009).

2.3. Psychological factors and noise sensitivity

2.3.1. There is considerable interaction between the psychological response to noise and sleep disturbance, each worsening the other. It is well recognised that psychological factors and personality traits influence the response to noise. Approximately 15% of the population are noise sensitive and have both a lowered annoyance level and an enhanced cortisol response, a physiological marker of stress. Noise sensitivity is considered to be a stable, partly heritable, personality trait; the noise sensitive being at one end of a continuum with the noise tolerant at the other. It is often implied that those who are highly annoyed by noise, including wind turbine noise, are motivated simply by a dislike of the noise source or are psychologically disturbed in some way. This is simply not the case, the response of the noise sensitive being as normal a reaction as that of the noise tolerant.

2.3.2. The noise sensitive are more likely to have stress related disorders, anxiety, headaches etc and poor sleep than the average. They are more likely to be found in the countryside where noise disturbance is less. Pedersen (2004)

reported that 50% of her rural subjects were rather or very noise sensitive. Noise sensitivity is more likely in those with brain injury and psychological disorders such as dyslexia and increased community noise may exacerbate depression in susceptible individuals.

Flindell and Stallen (1999) listed factors influencing the degree of annoyance to noise:

- Perceived predictability of the noise level changing
- Perceived control, either by the individual or others
- Trust and recognition of those managing the noise source
- Voice, the extent to which concerns are listened to
- General attitudes, fear of crashes and awareness of benefits
- Personal benefits, how one benefits from the noise source
- Compensation, how one is compensated due to noise exposure
- Sensitivity to noise
- Home ownership, concern about plummeting house values
- Accessibility to information relating to the noise source

to which may be added:

- Perceived value of the noise source
- Expectation of peace and quiet
- Visual impact

Disempowerment and loss of control is a common theme from reports of those subjected to excessive wind turbine noise. The impulsive character of the noise is perceived as threatening and it can not be escaped, being audible within the home, the usual source of refuge and quiet to permit restoration (Pedersen 2008). The end result is fear and anger at loss of control over the living environment with increased stress responses including increased difficulty in initiating and maintaining sleep. The increased wakefulness at night and the lower quality sleep increase the

impact of nocturnal turbine noise on sleep, increasing the daytime fatigue and stress and so on in a reinforcing cycle.

The psychological response to noise and noise sensitivity is a complex area and an excellent review is given by Shepherd, a psychoacoustician (Shepherd 2010).

3. Wind turbine noise, sleep and health

3.1. Introduction

3.1.1. The evidence above demonstrates that it is entirely plausible that wind turbine noise has the potential to cause arousals, sleep fragmentation and sleep deprivation. As noted above, the draft New Zealand standard on wind farm noise (2009) acknowledges that sleep disturbance is the major adverse consequence of wind turbine noise for humans.

3.1.2 Unfortunately all government and industry sponsored research in this area has used **reported awakenings** from sleep as an index of the effects of turbine noise and dismisses the subjective symptoms. Because most of the sleep disturbance is not recalled, this approach seriously **underestimates** the effects of wind turbine noise on sleep.

3.2. Early research.

3.2.1. Surveys of residents living in the vicinity of industrial wind turbines show high levels of disturbance to sleep and annoyance. A 2005 survey of 200 residents living within 1km of a 6 turbine, 9MW installation in France showed that 27% found the noise disturbing at night (Butre 2005). A similar US survey in 2001 (Kabes 2001) of a "wind farm" in Kewaunee County, Wisconsin reported that 52% of those living within 400-800 metres found the noise to be a problem, 32% of those living within 800-1600 metres and 4% of those within 1600 and 3200 metres. 67% of those living within 250 to 400 metres and 35% of those within 400-800 metres reported being awoken by

the sound in the previous year. The principal health problem reported by the 223 respondents was sleep loss. The landscape of Kewaunee County is described as "undulating to gently rolling". All of these studies were of smaller turbines than are currently proposed. Pedersen and Waye (2004) reported that "16% ($n=20$, 95%CI: 11%–20%) of the 128 respondents living at calculated external turbine noise exposure above 35.0 dB(A) stated that they were disturbed in their sleep by wind turbine noise." All of these studies use reported awakenings and may therefore underestimate the effects of wind turbine noise on sleep.

- 3.2.2. Phipps and others (2007) surveyed 1100 New Zealand households sited up to 3.5 km from a wind farm, 604 responded. 75% of all respondents reported being able to hear the noise. Two separate developments have placed over 100 turbines with capacities from 600kW to 1.65MW in a hilly to mountainous area. It has been suggested that mountainous areas may allow low frequency noise to travel further which may explain the long distance over which the turbines were heard. This suggestion tends to be confirmed by a recent study which is detailed below for convenience.

Phipps (2007a) has reported a further analysis of this data. All subjects lived more than 2km from the turbines, 85% living within 3.5km. 13% of 284 respondents heard the turbines at night either frequently or most of the time. 42 households reported occasional sleep disturbance from turbine noise and 26 were disturbed either frequently or most of the time. Phipps concludes that the New Zealand Standard for Wind Turbine Noise should be modified so that "the sound level from the wind farm should not exceed, at any residential site, and at any of the nominated wind speeds, the background sound level (L95) by more than 5 dBA, or a level of 30 dBA L95, whichever is less."

- 3.2.3. Bakker and colleagues (Bakker 2009) report their observations on noise problems, including sleep deprivation, associated with wind turbines at least 3km from the affected properties. The Tararua, New Zealand, turbines are sited on a ridge and the affected properties are to the east in a river valley.

Noise problems persisted despite the installation of sound reducing glazing. Nocturnal seismic noise monitoring showed noise bursts lasting at least 10 seconds, associated with an easterly wind, which the authors were confident originated from the turbines. The residents confirmed that the noise recorded was identical with that which disturbed their sleep. The authors speculate that the noise was transmitted through the ground. The importance of this report is not the mechanism for sound transmission but scientific confirmation that wind turbines can disturb sleep at distances of 3km. Previous anecdotal reports have often been dismissed as fanciful with assertions that sound transmission over such distances is impossible. While this seems, so far, to be an isolated case, it adds further evidence that much greater setbacks than those currently required are necessary to obviate sleep disturbance.

3.2.4. Van den Berg (2004) found that residents up to 1900 m from a wind farm expressed annoyance with the noise, a finding replicated in his more recent study reported below. Dr Amanda Harry (2007), a UK GP, conducted surveys of a number of residents living near several different turbine sites and reported a similar constellation of symptoms from all sites. A study of 42 respondents showed that 81% felt their health had been affected, in 76% it was sufficiently severe to consult a doctor and 73% felt their life quality had been adversely impacted. This study is open to criticism for its design which invited symptom reporting and was not controlled. While the proportion of those affected may be questioned it nevertheless indicates strongly that some subjects are severely affected by wind turbine noise at distances thought by governments and the industry to be safe.

3.3. Project WINDFARMperception

3.3.1. van den Berg and colleagues (2008) from the University of Groningen in the Netherlands have recently published a major questionnaire study of residents living within 2.5km of wind turbines, Project WINDFARMperception. A random selection of 1948 residents were sent a similar questionnaire to that used by Pedersen in her studies in Sweden.

(2003, 2004, 2007 and 2008), questions on health, based on the validated General Health Questionnaire (GHQ), were added. 725 (37%) replied which is good for a survey of this type but, nevertheless may be a weakness. Non-respondents were asked to complete a shortened questionnaire. Their responses did not differ from full respondents suggesting the latter are representative of the population as a whole.

Questions on wind turbine noise were interspersed with questions on other environmental factors to avoid bias. The sound level at the residents' dwellings was calculated, knowing the turbine type and distance, according to the international ISO standard for sound propagation, the almost identical Dutch legal model and a simple (non spectral) calculation model. The indicative sound level used was the sound level when the wind turbines operate at 8 m/s in daytime -that is: at high, but not maximum power. Ground absorption was set to 1.0, a 100% sound absorbing surface. Typical values are around 0.5 and thus the sound levels may have been underestimated. Noise exposure ranged between 24 and 54dB(A). It is worth noting that the wind industry was approached for assistance in the research but refused. Complaints such as annoyance, waking from sleep, difficulty in returning to sleep and other health complaints were related to the calculated noise levels.

Relevant conclusions include. *"Sound was the most annoying aspect of wind turbines"* and was more of an annoyance at night. Interrupted sleep and difficulty in returning to sleep increased with calculated noise level as did annoyance, both indoors and outdoors. Even at the lowest noise levels, 20% of respondents reported disturbed sleep at least one night per month. At a calculated noise level of 30-35dB(A), 10% were rather or very annoyed at wind turbine sound, 20% at 35-40dB(A) and 25% at 40-43dB(A) (the permitted minimum ETSU-R-97 night time level).

3.3.2. Project WINDFARM perception further found that *"Three out of four participants declare that swishing or lashing is a correct description of the sound from wind turbines. Perhaps the character of the sound is the cause*

of the relatively high degree of annoyance. Another possible cause is that the sound of modern wind turbines on average does not decrease at night, but rather becomes louder, whereas most other sources are less noisy at night. At the highest sound levels in this study (45 decibel or higher) there is also a higher prevalence of sleep disturbance." The lack of a control group prevents this group from making firmer conclusions about turbine noise and sleep disturbance but it is clear that as ETSU-R-97 permits an exterior night time noise level of 43dB, relying on its calculations will guarantee disturbed sleep for many of those living nearby.

3.3.3. van den Berg concluded also that, contrary to industry belief, road noise does not adequately mask turbine noise and reduce annoyance and disturbance. In addition, the authors compared their results with studies by Miedema on the annoyance from road, rail and air related noise. Wind turbine noise was several times more annoying than the other noise sources for equivalent noise levels (Fig 1). Similar data is given by Pedersen (2004) (Fig 2) – see end of text.

3.3.4 With regard to health it was concluded that: *"There is no indication that the sound from wind turbines had an effect on respondents' health, except for the interruption of sleep. At high levels of wind turbine sound (more than 45 dB(A)) interruption of sleep was more likely than at low levels. Higher levels of background sound from road traffic also increased the odds for interrupted sleep. Annoyance from wind turbine sound was related to difficulties with falling asleep and to higher stress scores. From this study it cannot be concluded whether these health effects are caused by annoyance or vice versa or whether both are related to another factor."* The conclusions regarding general health are not justified from the data for the reasons given below and must be disregarded.

3.3.5. Project WINDFARMperception is currently the largest study in this field but the study is not without considerable flaws. The study may be criticised for using calculated noise levels and for not having a control group (residents not living near turbines). While several of the contributors have expertise in

the investigation of health matters, none has specific expertise in the physiology and pathophysiology of sleep. The purpose of the study, as its title suggested, was the public perception of wind turbines and their noise. Health questions were added but were of a very general nature. The small number of respondents suggests that any conclusions as to the apparent lack of an effect on health must be regarded as tentative.

3.3.6. The analysis of reported sleep interruption and wind turbine sound levels is flawed by the use of subjects exposed to calculated external turbine sound levels of $<30\text{dB(A)}$ (p53) as the "controls". It has been noted by several studies that calculated turbine noise is often less than measured noise and that levels as low as 30dB(A) can cause annoyance (Pedersen 2007). Examination of the odds ratio for different calculated sound levels (Table 7.42) shows that it increases progressively with increasing sound levels starting at $30\text{-}35\text{dB(A)}$ and becomes statistically significant for levels $>45\text{dB(A)}$. If, as is not impossible, the "control" group had its sleep disturbed by wind turbine noise then the actual effect would be considerably underestimated.

3.3.7. The major objection to the conclusions on health is that the study is grossly under-powered (insufficient subjects were studied for any degree of statistical confidence). Marked ill-health, "Wind turbine syndrome", to the degree reported by Pierpont (2009), does not seem to be common even amongst those exposed to high noise levels. The study tried to detect chronic disease with the GHQ, which is a fairly crude instrument. Assuming that "wind turbine syndrome" affects 1% of those exposed to calculated sound levels $>45\text{dB(A)}$ and that 25% of the general population suffer from chronic disease (p47) then at least 30,000 subjects would need to be studied in each group ($<45\text{dB(A)}$ v $>30\text{dB(A)}$) to be able to prove a difference with 95% certainty. Even if a prevalence of "wind turbine syndrome" of 5% of those exposed to $>45\text{dB(A)}$ is assumed, then there must be at least 1250 subjects in each group. It is possible also that those with a degree of ill health are more vulnerable and more likely to develop symptoms. A general health questionnaire will not detect such people and

symptom specific surveys will be required. This study therefore can not conclude that wind turbines do not cause ill health of any degree, it can not even make conclusions about severe ill health.

3.3.8. Pedersen, van den Berg and others (Pedersen 2009a&b) have further analysed the data in an attempt to model a generalised dose-response relationship for wind turbine noise. A noise metric, Lden, was calculated (Miedema 2000). Lden is based on long-term equivalent sound pressure levels adjusted for day (d), evening (e) and night). Penalties of 5 and 10dB are added for evening and night hours to reflect the need for quietness at those times. dB(A) values for wind turbines may be transformed to Lden values by adding 4.7 ± 1.5 dB (van den Berg 2008). Annoyance is used as the principal human response to wind turbine noise in this analysis. In this context, "annoyance" is more than simply irritation but is a measure of lack of well-being in a wider sense (Pedersen 2009a) and is contrary to the WHO definition of health.

Annoyance increased with increasing sound levels, both indoors and outdoors. The proportion who were rather and very annoyed at different sound levels are shown in Table I. In summary, when outside, 18% were rather or very annoyed at sound levels of 35-40 and 40-45 dB(A) compared to 7% at 30-35dB(A) and 2% at <30dB(A). When inside, the equivalent figures were 1% at <30dB(A), 4% at 30-35dB(A), 8% at 35-40dB(A) and 18% at 40-45dB(A). Those respondents who had an economic interest in the turbines had lower levels of annoyance while negative views of the visual impact of turbines increased the likelihood of annoyance.

Although the authors do not seek to recommend minimum sound levels, they do note that turbine noise was more annoying than other sources, with the possible exception of railway shunting yards and was more noticeable at night. They conclude that: *"...night time conditions should be treated as crucial in recommendations for wind turbine noise limits."* Nevertheless, it is clear from this analysis that external predicted turbine sound levels should

be less than 35dB(A), considerably less than those permitted by ETSU R 97, in order to reduce effects on nearby residents to acceptable levels.

3.3.8. Pedersen (2009a&b) has recently combined the datasets from three studies (Pedersen 2004 (SWE00)) and 2007 (SWE05) and van den Berg 2008 (NL07)) as they used similar questionnaires giving a total of 1764 subjects. A strong correlation was seen in all studies between calculated A weighted sound pressure levels and outdoor annoyance as noted above.

Even at sound pressures of 30-35 dB(A), 5-12% of subjects were very annoyed. Correlations were found also between annoyance and symptoms of stress (headache, tiredness, tension and irritability) confirming that "annoyance" is more than irritation and is a marker of impaired health. The sleep disturbance question did not ask causation of the sleep disturbance and a background level would therefore be expected from other causes (traffic noise, weather, etc). Nevertheless, there was a clear increase in levels of sleep disturbance with A-weighted sound pressure in studies SWE00 and NL005. (Figure 3). Pedersen states *"In the first Swedish study (SWE00) the increase of respondents that reported sleep interruption appears to be between the sound level interval 35-40 dB(A) and 40-45 dB(A). The increase came at higher sound levels in the Dutch study (NL07); between the interval 40-45 dB(A) and >45 dB(A)"*. There is no true measurement of background levels of sleep disturbance as no study had a control group, it is difficult therefore to determine at what sound pressure level turbine noise begins to have an effect. but even the conservative levels suggested above are less than those permitted by ETSU R 97. Fig 3 see end of text.

3.3.9. Jabben and colleagues (2009) from RIVM, the Dutch National Institute for Public Health and Environment, were commissioned by the Dutch Government to examine the impact of different values of Lden on the ability to meet targets for onshore wind power generation. They reviewed current evidence and noted that, at present, 440,000 inhabitants (2.5% of the population) were *"receiving significant noise contribution from wind turbine*

noise of which 1,500 are expected to suffer severe annoyance. It is remarkable that almost half of this number already occurs within the range Lden 30-40db(A)". Despite this, they recommend an Lden of no more than 40dB(A), which corresponds to a calculated external turbine noise level of about 35.3dB(A), in order for the Dutch Government to meet its 2011 target for wind turbine installations.

3.3.10. All of the studies cited in this section have used reported sleep disturbance and annoyance in determining maximum sound levels. As noted in Section 2.2, reported sleep disturbances underestimate sleep disturbance and may not reflect actual physiological consequences. The precautionary principle demands that lower sound levels be selected in order to leave a margin of safety.

3.4. Pierpont studies

3.4.1. Pierpont (2009) has recently completed a detailed case-series study of 10 families around the world who have been so affected by wind turbine noise that they have had to leave their homes, nine of them permanently. Subjects were selected from respondents to an appeal for those regarding themselves as suffering from ill health as a result of exposure to turbine noise. The turbines ranged from 1.5 to 3MW capacity at distances between 305 to 1500m. The group comprised 21 adults, 7 teenagers and 10 children of whom 23 were interviewed. While this is a highly selected group, the ability to examine symptoms before, during and after exposure to turbine noise gives it a strength rarely found in similar case-series studies. The subjects described the symptoms of wind turbine syndrome outlined above and confirmed that they were not present before the turbines started operation and resolved once exposure ceased. There was a clear relationship between the symptoms, even in children, and the noise exposure. Pierpont reports also that all adult subjects reported "*feeling jittery inside*" or "*internal quivering*", often accompanied by anxiety, fearfulness, sleep disturbance and irritability. Pierpont hypothesises that these symptoms are related to low frequency sound and suggests

physiological mechanisms to explain the link between turbine exposure and the symptoms.

3.4.2. Of particular concern were the observed effects on children, include toddlers and school and college aged children. Changes in sleep pattern, behaviour and academic performance were noted. 7 of 10 children had a decline in their school performance while exposed to wind turbine noise which recovered after exposure ceased. In total, 20 of 34 study subjects reported problems with concentration or memory.

3.4.3. Pierpont's study mostly addresses the mechanism for the health problems associated with exposure to wind turbine noise rather than the likelihood of an individual developing symptoms. Nevertheless, it convincingly shows that wind turbine noise is strongly associated with the symptoms she describes, including sleep disturbance. She concludes by calling for further research, particularly in children, and a 2km setback distance.

3.4.4. A recent paper (Todd et al, 2008) has shown that the vestibular system in the human ear, the part concerned with detection of movement and balance, is exquisitely sensitive to vibration at frequencies of around 100Hz. Pierpont claims that these findings support her hypotheses.

3.4.5. Leventhall, formerly Professor and Head of the Institute of Environmental Engineering at South Bank University and an expert on low frequency noise, accepts that the symptoms described by Pierpont's subjects are real but maintains that the low frequency sound energy created by wind turbines is too low to cause direct physiological effects (Pool, 2009 and personal communication 2009). He suggests that the symptoms are a result of psychological stress secondary to noise annoyance, particularly low frequency noise and sleep disturbance. Similar symptoms were described by Nagai et al (1989) and Møller and Lydolf (2002).

The NHS Knowledge Service reviewed Dr Pierpont's paper (NHS 2009) and concluded: *"No firm conclusions can be drawn from this study as the design*

was weak and included only 38 people. Participants were asked about their symptoms before they were exposed to wind turbines to provide a control for their symptoms after exposure. This was not a sufficient control as many of the participants were reportedly already convinced that wind turbines caused their symptoms and were actively trying to move out of their homes or had already moved. Further study is needed."

The call for further research has been heeded in Japan; Yomiuri Shimbun (November 29th 2009), a leading Japanese newspaper, reports that the Japanese Environment Ministry has commissioned a four year study into the effects of low frequency wind turbine noise on human health. The question as whether "wind turbine syndrome" is a distinct clinical entity remains unsettled at this time.

Another Japanese newspaper, Asahi Shimbun, (Ito and Takeda 2009) in a report of the decision of the Japanese Environment Ministry to investigate the potential health effects of wind turbine noise has reported its own survey of complaints of wind turbine noise directed at state and local authorities and wind turbine operators in Japan. 30 of 376 locations (8%) had received complaints, 90% of which concerned health problems which included insomnia, headaches, dizziness and buzzing in the ear.

Izumi Ushiyama, president of the Ashikaga Institute of Technology and an expert on wind power generation, is quoted as saying that: *"operators must listen to residents before pushing their projects. Some operators make light of communications with residents in carrying out their projects, which causes friction. This has tarnished the image of wind power generation and blocked its promotion."*

Ushiyama is quoted also as saying that a third-party "communicator," trusted by both operators and residents, must be called upon to make adjustments because the two sides may become involved in confrontations if left alone to discuss the issue.

This report shows that not only are complaints about wind turbine noise consistent across cultures so also are the symptoms.

3.5. DTI report

3.5.1. The wind industry relies on a DTI report by the Hayes McKenzie Partnership (HMP) published in 2006 which investigated low frequency noise at three UK wind farms. As far as can be determined, no medical or physiological expertise was used in the design of the study. Sound measurements were taken at three of five sites where complaints had been recorded over periods from 1-2 months.

Communication with residents other than those who complained was minimal. However, they did confirm that *"some wind farms clearly result in modulation at night which is greater than that assumed with the ETSU-R-97 guidelines"*. Measured *"internal noise levels were insufficient to wake up residents at these three sites. However, once awoken, this noise can result in difficulties in returning to sleep."*

The lack of physiological expertise in the investigators in not recognising that noise can disturb sleep without actual recalled awakening is a major methodological flaw rendering the conclusions unreliable, as is the short recording period. It is well recognised also that not every resident affected by a nuisance such as noise will actually register a complaint (Health Protection Agency 2009). Many will not be sufficiently literate or confident so to do and others may wish to avoid drawing attention to the problem to protect property prices. They may assume also that protest is futile, which seems to be the experience of many with wind turbine noise. Recorded complaints are thus the tip of the iceberg.

3.5.2. It is often claimed also that only 5 of 126 wind energy developments at the time of the study had attracted complaints of noise and thus the matter is trivial. This assertion is, to say the least, disingenuous. Many of the developments at that time were of small turbines set in isolated areas of the

countryside, well away from habitation. In addition, as noted above, the proportion of those affected by wind turbine noise who formally complain to their local authority is very small. Research into wind farm noise and health issues in the UK is virtually non-existent and of poor quality. To suggest that there is "no problem" when faced with the large body of evidence presented here is perverse. The conclusion is also contradicted by Moorhouse's study (vide infra) which showed a complaint rate of 20%.

3.5.3. Draft versions of the report (DTI 2006a,b,c) have recently come to light as a result of Freedom of Information requests. They show that HMP had recommended a reduction of the ETSU-R-97 permitted night time limits to 38dB LA90 (40dB LAeq) in the absence of AM with a further penalty of up to 5dB in the presence of modulation. These recommendations were removed from the final version of the report. No scientific explanation for their removal seems to have been offered. An example of removed text follows:

"The analysis of the external and internal noise levels indicates that it may be appropriate to re-visit the issue of the absolute night-time noise criterion specified within ETSU-R-97. To provide protection to wind farm neighbours, it would seem appropriate to reduce the absolute noise criterion for periods when background noise levels are low. In the absence of high levels of modulation, then a level of 38 dB LA90 (40 dB LAeq) will reduce levels to an internal noise level which lies around or below 30 dB LAeq with windows open for ventilation. In the presence of high levels of aerodynamic modulation of the incident noise, then a correction for the presence of the noise should be considered."

Similarly, references to WHO guidance for the protection of sleep disturbance which supported HMP's recommendations for a reduction in ETSU-R-97 night time noise limits were removed. The removed text follows:

"If one takes the guidance within the WHO for the protection against sleep disturbance of 30dB LAeq, and apply a 5 dB correction for the presence of high levels of [aerodynamic] modulation within the incident noise, then this

gives rise to an internal noise criterion of 25dB LAeq. Based upon the measured building attenuation performances at Site 1 & 2, then an external level between 35 – 40dB LAeq (33-38 dB LA90) would provide sufficient protection to neighbouring occupants to minimise the risk of disturbance from the modulation of aerodynamic noise."

It is quite clear that relying on the conclusions of this report, as published, is unwise as they are, at best, misleading.

3.6. Salford study

3.6.1. The wind industry refers to a report by Moorhouse and others of the University of Salford, commissioned by DEFRA into Aerodynamic Modulation of Wind Turbine Noise published in 2007. A survey was made of the UK local authorities responsible for wind farms in, or adjacent to, their area. 133 wind farms were identified of which 27 (20%) had attracted complaints. An attempt was made to correlate complaint logs with recorded wind speed and direction. Once again the methodology is fundamentally flawed. Complaints were solicited from local authorities and not from residents. The review was entirely theoretical with no communication with residents. The conclusions were that AM was such a minor problem that no further research was warranted.

3.6.2. The Editor of Noise Bulletin greeted the publication of the report thus:

"New report eases concerns over wind turbine noise' trumpets the Government press release, then saying aerodynamic modulation is 'not an issue for the UK's wind farm fleet'. This conclusion is not justified based on the report, and by halting further research work without transparently monitoring the wind farms subject to complaints will inflame, not ease concern of objectors ... Only when the public can trust the Government and wind farm developers on noise issues will there be a chance that the public will accept them without a fight ..."

(Pease J. Noise Bulletin, Issue 15, Aug/Sept. 2007 page 5).

- 3.6.3. On 2 August 2007, Dick Bowdler, an acoustician and member of the Noise Working Group which commissioned the report, resigned from the NWG. This highly unusual step was taken because, as his letter states:

"I have read the Salford Report and the Government Statement. As a result I feel obliged to resign from the Noise Working Group.

The Salford Report says that the aims of this study are to ascertain the prevalence of AM from UK wind farm sites, to try to gain a better understanding of the likely cause, and to establish whether further research into AM is required. This bears little relation to what we asked for which is clearly set out in the minutes of the meeting in August 2006. We all knew then (as was recorded in the original notes of the meeting) that complaints concerning wind farm noise are currently the exception rather than the rule. The whole reason for needing the research was that 'The trend for larger more sophisticated turbines could lead to an increase in noise from AM'.

It was not the intended purpose of the study to establish whether more research was required. We all agreed at the August 2006 meeting that such research was needed. That was precisely the outcome of the meeting. The prime purpose of what eventually became the Salford Report was to identify up to 10 potential sites which could be used to carry out objective noise measurements. The brief for the Salford report, which was never circulated to the NWG, completely ignored the NWG views.

Additionally, I find it entirely unacceptable that we are not to be told the names of the wind farms listed in the Salford report. So the only part of the report of any value to assist future research is inaccessible to those of us who would like to progress matters further.

Looking at the Government Statement it is clear that the views of the NWG (that research is needed into AM to assist the sustainable design of wind farms in the future) have never been transmitted to government and so the Statement is based on misleading information".

(Noise Bulletin, Issue 15, Aug/Sept. 2007 page 5)

- 3.6.4. If both a leading commentator in the field and a leading member of the Government's own working group have no faith in the study then its conclusions may safely be dismissed.
- 3.6.5. Following a refusal by the Salford research team and the DTI to share the study's full data, the actual questionnaire response forms were finally made available after a Freedom of Information request by the Renewable Energy Foundation. The low quality of this research is evident from the poor responses from many local authorities, compounded by the questionnaire design and the phrasing of the questions. This further serves to demonstrate that current planning guidance, and in particular ETSU-R-97, are inadequate at preventing noise annoyance.

3.7. Acoustician opinions

3.7.1. George Kamperman, (2008 personal communication) a distinguished US noise engineer, is quoted in Pierpont's book as saying, *"After the first day of digging into the wind turbine noise impact problems in different countries, it became clear the health impact on persons living within about two miles from 'wind farms' all had similar complaints and health problems. I have never seen this type of phenomenon [in] over fifty plus years of consulting on industrial noise problems. The magnitude of the impact is far above anything I have seen before at such relatively low sound levels. I can see the devastating health impact from wind turbine noise but I can only comment on the physical noise exposure. From my viewpoint we desperately need noise exposure level criteria."* Kamperman's recommended setback of at least 1km (Kamperman & James 2008) has changed to at least 2km as a result of Dr Pierpont's evidence (Kamperman 2008 personal communication). He has recently published a more detailed set of recommendations to determine setback distances (Kamperman & James 2008b) which, amongst others, require that turbine noise should not be more than 5dB(A) above background and should not exceed 35dB(A) within 30m of any occupied structure.

3.7.2. Dr Robert Thorne, an Australian acoustician has investigated wind turbine noise at several sites in Australia and New Zealand. His conclusions can be found in several expert reports submitted to Planning Inquiries, most recently Turitea (Thorne 2010a) and Yaloak (Thorne 2010b). He states (Thorne 2010b para 6.18):

"I am of the opinion, based on my own research, that wind farm noise can and does create unreasonable noise within residences and consequential adverse effects in the sense of sleep disturbance, annoyance and potential adverse health effects to residents living within 2000 metres of large wind turbines set in a wind farm. These risks are quantifiable and are of high probability. The effect is significantly more than minor."

3.8. Recent Research

3.8.1 WindVOiCe recently published the updated results of a self-reporting survey of communities affected by wind turbine noise. As of March 2010, 141 responses had been received of which 115 reported one or more health effects. 83 of the 115 (72%) reported sleep disturbance. There were no age differences between those that reported sleep disturbance (51.5 yr (19-79)) and those that did not (52.2 yr (26-86)).

Those that reported sleep disturbance lived an average of 897m (360-5000) from turbines compared to 890m (350-3500) for those who did not. The similarity in distance from turbines for the two groups suggests that noise sensitivity may be significant factor in sleep disturbance. A slightly greater proportion of females reported sleep disturbance than males (24/43 (56%) vs 23/51 (45%)). Caution must be exercised in drawing conclusions from self reporting surveys. Nevertheless, it is evident that significant numbers of individuals are reporting sleep disturbance and health issues at distances considerably greater than those currently deemed safe. All but five of those reporting sleep disturbance live within 1500m of the turbines adding further support to a minimum setback of at least that distance.

3.9. World Health Organisation/European Community recommendations

3.9.1. The WHO Regional Office for Europe in collaboration with the EU established a working party in 2003 to examine the effects of night time noise on sleep disturbance and health. Their brief was to review the current evidence and produce recommendations on permissible night time noise levels. Inevitably, the work concentrates on road traffic and aircraft noise as generating the most complaints and the subjects of most research.

3.9.2. A preliminary report was published in 2007 (WHO 2007). They reported that:

"The review of available evidence leads to the following conclusions.

- *Sleep is a biological necessity, and disturbed sleep is associated with a number of adverse impacts on health.*
- *There is sufficient evidence for biological effects of noise during sleep: increase in heart rate, arousals, sleep stage changes, hormone level changes and awakening.*
- *There is sufficient evidence that night noise exposure causes self-reported sleep disturbance, increase in medicine use, increase in body movements and (environmental) insomnia.*
- *While noise-induced sleep disturbance is viewed as a health problem in itself (environmental insomnia) it also leads to further consequences for health and well-being.*
- *There is limited evidence that disturbed sleep causes fatigue, accidents and reduced performance.*
- *There is limited evidence that noise at night causes clinical conditions such as cardiovascular illness, depression and other mental illness. It should be stressed that a plausible biological model is available with sufficient evidence for the elements of the causal chain."*

"For the primary prevention of subclinical adverse health effects in the population related to night noise, it is recommended that the population should not be exposed to night noise levels greater than 30 dB of $L_{\text{night, outside}}$ during the night when most people are in bed. Therefore, $L_{\text{night, outside}}$ 30 dB is the ultimate target of Night Noise Guideline (NNGL) to protect the public, including the most vulnerable groups such as children, the chronically ill and the elderly, from the adverse health effects of night noise."

The report described a new noise metric, $L_{\text{night, outside}}$, which is the yearly average of night noise level outside the facade. This seems to have been chosen as more appropriate for health effects that require long term noise exposure, such as high blood pressure, than those related to short term disturbance such as sleep disturbance and insomnia.

3.9.3. A further report was published in 2009 (WHO 2009). A similar approach was taken to that of Pedersen (2009a&b) and the report seeks to establish a No Observed Effect Level (NOEL) and a Lowest Observed Adverse Effect level (LOAEL) for noise and various measures of health. While a useful approach, it must be remembered that the LOAEL will vary with the noise frequency and pattern, the age of the subjects studied and the sensitivity of the measurement of the effect. There will also be a range of LOAEL within the

population depending upon noise sensitivity. Allowance should be made for those who are most sensitive. With respect to noise and health, it can not be assumed that all noise is the same; as noted above, several studies have shown that wind turbine noise is more annoying than traffic or aircraft noise. Children and the elderly may be more sensitive than adults who are studied most often. While blood pressure and heart attacks are well defined and easily measured, sleep disturbance, fatigue, mood and similar subjective symptoms are less easily measured and distinguished from the background levels present in the population.

An $L_{\text{night,outside}}$ of 40dB was recommended as representing the LOAEL. They state for $L_{\text{night,outside}}$ of 30-40dB:

"A number of effects on sleep are observed from this range: body movements, awakening, self-reported sleep disturbance, arousals. The intensity of the effect depends on the nature of the source and the number of events. Vulnerable groups (for example children, the chronically ill and the elderly) are more susceptible. However, even in the worst cases the effects seem modest. $L_{\text{night,outside}}$ of 40 dB is equivalent to the lowest observed adverse effect level (LOAEL) for night noise."

3.9.4. The recommendation that an $L_{\text{night,outside}}$ of 40dB should be the night noise guideline for Europe seems perverse in the light of the conclusions of the effects of sound levels between 30 and 40dB above. A value of 21dB was used for sound attenuation from outside a building to inside. This is greater than the 10-15dB usually cited. Bearing in mind the reservations expressed in Section 3.9.3 and, in particular the nature of wind turbine noise, an external noise level of 40dB must be regarded as the absolute maximum permissible and must be fully justified. Noise exposure above this level will be associated with a risk of ill health. Kamperman and Pedersen's recommendations of a maximum external limit of 35dB(A) and HMP's recommendations of 33-38 dB(A) would be appropriate for wind turbine noise to prevent annoyance and sleep disturbance and is supported by the WHO/EU findings quoted above.

- 3.10. Nissenbaum (2010) has presented the preliminary results of a study of residents living downwind and within 300-1100m (mean 800m) of a wind farm at Mars Hill, Maine, USA. The 28 1.5MW turbines are sited on a 200m high ridge overlooking the homes. 22 of about 35 adult residents have been interviewed so far and compared with a randomly selected control group living a mean 6km away. 18/22 reported new or worsened sleep onset disturbance at least twice a week, for 9 at least 5 times per week (controls 1/28). 8/22 reported new or worsened headaches (controls 1/28) and 18/22 reported new or worsened mental health symptoms (stress 12/22, anger 18/22, anxiety 8/22, hopelessness 12/22, depression 10/22) (controls 0/28).

The 22 subjects received 15 new or increased prescriptions from their physicians in the 18 months between the start of turbine operation and the study, the majority for psychoactive medication (controls 4 prescriptions, none for psychoactive medication). 21/22 reported reduced quality of life and 20/22 considered moving away (controls 0/28 for both).

The study may be criticised for its relatively small numbers of subjects but the presence of a control group, well matched for age and gender, adds considerable power. All differences between the groups are statistically highly significant. The turbine noise levels may be enhanced by the high concentration of turbines and the geography but the severe sleep disturbance, psychiatric symptomatology and increased medication requirement in the study group confirms the potential of wind turbine noise to adversely affect health at distances claimed to be safe.

- 3.11. The American and Canadian Wind Energy Associations (A/CanWEA) have recently commissioned a review of the literature on wind turbine noise and health effects (Colby et al. 2009). The panel concluded that:

- *There is no evidence that the audible or sub-audible sounds emitted by wind turbines have any direct adverse physiological effects.*
- *The ground-borne vibrations from wind turbines are too weak to be detected by, or to affect, humans.*

- *The sounds emitted by wind turbines are not unique. There is no reason to believe, based on the levels and frequencies of the sounds and the panel's experience with sound exposures in occupational settings, that the sounds from wind turbines could plausibly have direct adverse health consequences."*

The quality and authority of this review and its conclusions are open to considerable doubt. The medical members of the panel comprised a microbiologist, an otolaryngologist and an occupational health physician specialising in respiratory disease. From their biographies, none seems to have any expertise in sleep medicine or in psychology. The reference list shows that the literature review was far from complete. The panel admits that wind turbine noise causes annoyance which can lead to sleep disturbance but dismisses these findings. It is clear that they did not understand the significance of "annoyance" in a health context and neither did they comprehend the importance of sleep disturbance in causing ill-health.

The NHS Knowledge Service reviewed the paper (NHS 2010) and concluded: *"This research is unlikely to resolve the controversy over the potential health effects from wind turbines. This is mainly because the research on which the review was based is not sufficient to prove or disprove that there are health effects. The review itself also had some methodological shortcomings, and the reviewing group did not include an epidemiologist, usually a given for assessing potential environmental health hazards. Further research on this issue is needed."*

The Society for Wind Vigilance (Horner et al. 2010) has reviewed the A/CanWEA paper, publishing a detailed critique, and concluded: *"It is apparent from this analysis that the A/CanWEA Panel Review is neither authoritative nor convincing. The work is characterized by commission of unsupportable statements and the confirmation bias in the use of references. Many important references have been omitted and not*

considered in the discussion. Furthermore the authors have taken the position that the World Health Organization standards regarding community noise are irrelevant to their deliberation - a remarkable presumption."

3.12. Conclusions

3.12.1. The quality of the research in this area is very variable. Most are surveys using self-completed questionnaires. Response rates have generally been good for this type of enquiry, which may reflect the public interest and concern that wind turbines generate. Nevertheless, it is inevitable that it is more likely that those who feel they have been affected will respond rather than those who have not. The questionnaires themselves have not always been well drafted. Most do not have a control group, a separate group not exposed to turbine noise with whom to make comparisons. The studies are all post hoc, initiated after the turbines have been operating and generally in response to complaints. The lack of pre-exposure data weakens the studies but does not invalidate them totally. Many of the authors have been criticised for their presumed lack of expertise in this area. Because governments and industry have refused funding and co-operation, individuals have had to rely on their own resources in order to conduct research, which though propelled by a concern for public health, has also enforced limits on their extents. Initial clinical investigations often rely on self-completed questionnaires in order to define, refine, and establish future research projects and this work should not simply be dismissed.

Nevertheless, the number of reports and weight of evidence demonstrating impacts on sleep quality and health of wind turbine noise from existing installations is such that it can be firmly concluded that present guidance to determine setbacks is inadequate.

3.12.2. The UK government, in acknowledging the deleterious effect of noise on human well-being, have recently published two reports through the Health Protection Agency (HPA 2009) and DEFRA (Berry and Flindell, 2009). The former, which is in draft form awaiting comments, reviews the evidence for the effects of noise on health. Traffic, aircraft, railway and industrial noise is considered but, surprisingly, there is no consideration of wind turbines despite the government's plans for a major increase in size and capacity and their proposed placement in generally previously tranquil but well

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populated areas of countryside. The report calls for more research, including in the areas of sleep disturbance, cardiovascular effects and children's health. They commend the use of dose-response relationships to inform planning policy. The latter report reviews dose-response relationships between noise exposure and human health and concludes that such is a useful approach worthy of further research. They commend the work of RIVM, who were extensively consulted in preparing the report.

3.12.3. The recent analyses of the WINDFARM Perception and earlier Swedish studies by Pedersen and her colleagues gives, for the first time, robust evidence that wind turbines cause sleep disturbance and impair health and that this occurs at set-back distances previously regarded as adequate. However, it must be noted that the measures used in these studies are relatively imprecise. As noted in Section 2.2, arousals due to noise are several times more likely to occur than awakenings but are as destructive to sleep quality. More precise measures such as the Brief Fatigue Inventory or direct assessment of sleep quality are needed to determine a correct dose-response relationship between turbine noise and sleep disturbance. In the meantime, the precautionary principle should prevail and setbacks determined appropriately.

3.12.4. In weighing the evidence, I find that, on the one hand, there are large numbers of reported cases of sleep disturbance and other adverse effects on health, as a result of exposure to noise from wind turbines, supported by an increasing number of research reports that confirm the validity of the anecdotal reports and provide a reasonable basis for the complaints. On the other, we have badly designed, and improperly edited, industry and government reports, which seek to show that there is no problem. I find the latter unconvincing.

3.12.5. The recent RIVM and WHO reports and the draft DTI/HMP reports confirm the potential for noise to adversely effect health through sleep disturbance and set maximum permissible noise levels which are less than those permitted by ETSU-R-97.

3.12.6. In my expert opinion, from my knowledge of sleep physiology and a review of the available research, I have no doubt that wind turbine noise emissions have been clearly associated with sleep disturbances.

Further, the evidence now available is quite clear that present UK noise guidelines are inadequate to protect the sleep of residents living too close to wind turbines.

4. Preventing sleep disturbance from wind turbine noise.

4.1 Background

4.1.1. Developers of noisy industrial processes, including wind turbines, seek to mitigate the disturbance by siting them in areas of high ambient noise, such as close to major roads. In the case of wind turbines, it is assumed that rising wind speed will not only increase turbine noise but ambient noise also. The degree to which this occurs depends on the proximity of vegetation and other structures. Motorway noise diminishes at night as the volume of traffic decreases. In addition, it is common for wind speeds to diminish at ground level as night falls while being maintained at turbine hub level, wind shear (Pedersen E and Persson Wayne K. 2003, Schneider 2007). In both cases, the turbine noise will be much more audible as ambient noise decreases and explains why complaints of nocturnal noise and disturbed sleep are common. The importance of wind shear has been acknowledged in a recent technical contribution to Acoustics Bulletin (March/April 2009) from some members of the NWG calling for all noise levels to be referenced to wind speed at turbine hub height. Conditions which favour wind shear also favour amplitude modulation (Palmer 2009). Temperature inversion, where ground level air is cooler than higher level air also increases sound propagation by reflection of the noise from the boundary layer (Irvine. 2009). These conditions, which are most likely to occur at night, early morning and in winter have not received as much attention as wind shear but may be a further reason why turbine noise may be heard over greater distances than predicted.

4.1.2. Schneider (Schneider 2007) found that night time turbine noise was between 3 and 7dB(A) greater than predicted during periods of atmospheric stability: *"summer, night-time noise levels exceeded levels predicted for two sites within the Maple Ridge Wind Farm. For winds above generator cut-in speed (e.g., 3.0 m/s @ 80-m), the measured noise was 3-7 dBA above predicted levels. The decoupling of ground level winds from higher level*

winds, i.e., atmospheric stability, was apparent in the noise data at both sites during evening and night-time periods. At wind speeds below 3.0 m/s, when wind turbines were supposedly inoperative, noise levels were 18.9 and 22.6 dBA above the expected background levels for each of the sites and these conditions occurred a majority of the time."

In addition, as noted above, the characteristics of wind turbine noise are such that it can be heard despite road noise.

4.1.3. van den Berg, in a paper presented at Euronoise 2003, investigated the relationship between calculated noise generated by wind turbines and that actually measured. He confirmed that the turbines were more audible at night principally due to amplitude modulation. To quote his paper: *"As measured immission levels near the wind park Rhede show, the discrepancy may be very large: sound levels are up to 15 dB (!) higher than expected at 400 m from the wind park. At a distance of 1500 m actual sound levels are 18 dB higher than expected, 15 dB of this because of the higher sound emission and 3 dB because sound attenuation is less than predicted by the sound propagation model."* An 18dB increase is equivalent to an 8 fold increase in sound pressure and a 15dB change is a 6 fold increase. An 18dB increase is close to a three fold increase in perceived loudness. From this study, it would appear that calculated measures of wind turbine noise are woefully inadequate.

4.1.4. In contrast, Bullmore and colleagues (2009) reported, from studies of four established large wind farms, that ISO 9613 predicted turbine noise immissions with reasonable accuracy and, at three of the sites, over estimated the measured sound levels. However, the actual location of the sites was not revealed although some detail was given. No attempt was made to determine the degree of wind shear during the measurement period.

4.1.5. Nelson (2007), in a small laboratory-based study examined the ability of background noise to mask turbine noise. When background noise and

turbine noise where adjusted to the same loudness, the residual perceived loudness of the turbine noise was approximately half of its unmasked value (1.8sone). Even when the background noise was increased from 41 to 49dB(A) the turbine noise was not fully masked. Hayes (2007) has interpreted this by stating that: *"one would expect the wind turbine (warranted to be free of tonal noise) to be audible even if the turbine noise was 10 - 15 dB below the background noise level"*. It can be inferred that if tonal noise is present, the turbine noise will be audible at a greater level below background noise.

- 4.1.6. Bolin (2009) has reported an experimental study of the masking of wind turbine noise by vegetation noise (leaves rustling etc). Subjects were exposed to vegetation noise in a laboratory and turbine noise introduced at varying sound pressures and vice versa and a threshold for detection determined. The results were compared with the Moore and Glasberg methods for calculating masking. The results suggest that: *"...existing models of partial masking overestimate the ability to conceal wind turbine noise in ambient sounds."* In other words, wind turbine noise is not masked as well as current models predict and is thus more intrusive. This is in accord with the work of Nelson and of van den Berg and Miedema who show that background and traffic noise do not mask wind turbine noise as well as predicted.

4.2. Mitigation of wind turbine noise

4.2.1. Bowdler (2008) has recently reviewed the causation of the swishing and thumping noises associated with wind turbines. He concludes that, while there are several theories, no definitive mechanism can be established. It follows that industry claims to mitigate turbine noise by changing blade shape, pitch and turbine spacing should be treated with scepticism until definitive evidence of their efficacy are presented.

4.2.2. It follows that attempts to reduce wind turbine noise immissions after a plant becomes operational are unlikely to be successful. Noise mitigation will reduce power output, which will be opposed by the operators. The importance of assuring residents that noise limits are capable of being met before construction was emphasised by Mr Lavender, Inspector at the Thackson's Well Inquiry (APP/E2530/A/08/2073384) who stated: *"securing compliance with noise limit controls at wind farms, in the event of a breach, is not as straightforward as with most other forms of noise generating development. This is because noise from turbines is affected primarily by external factors such as topography and wind strength, a characteristic that distinguishes them from many other sources of noise, such as internal combustion engines or amplified music, which can be more directly and immediately influenced by silencing equipment, insulation or operator control."* It follows that application of the precautionary principle is essential where there is any possibility of noise disturbance from wind turbines.

4.2.3. Thus, the **only** mitigation for wind turbine noise is to place a sufficient distance between the turbines and places of human habitation. PPS22 advises that ETSU-R-97 *should* (author's italics) be used to estimate noise levels around turbines which, taken with measurements of ambient noise, can, in theory, predict noise disturbance in adjacent properties. Many expert acousticians have severely criticised ETSU-R-97, not least Mr Dick Bowdler (2007), a former member of the Government's Noise Working Group considering ETSU-R-97. A number of Her Majesty's Inspectors have been

equally critical, not least Mr Andrew Pykett (Appeal Ref: APP/Q1153/A/06/2017162) and Ms Elizabeth Ord (APP/W4705/A/09/2114165). As noted above, the recent recommendation by some members of the Noise Working Group to provide more allowance for wind shear in predicting turbine noise levels is a tacit admission of the unsuitability of ETSU-R-97 methodology for large turbines. In addition the suppressed recommendations by HMP, at least one of whose employees sat on the NWG, for a reduction in the ETSU-R-97 night time noise limits to 33-38dB(A) suggests very strongly that it is inappropriate to continue to rely on ETSU-R-97 as presently formulated.

4.2.4. Stigwood (2008) has shown that large turbines (hub heights 50-100m) are more likely than smaller turbines (hub height 30m) to cause excessive amplitude modulation, increased likelihood of low frequency noise and greater disturbance inside buildings. Internal noise can modulate over 15-20dB, changes which are easily perceived. This is probably due to different wind speeds and atmospheric conditions at these heights. He concludes that ETSU-R-97, which was developed for smaller turbines, is inappropriate for large turbines.

4.2.5. Despite, or because of, ETSU-R-97, complaints of noise disturbance from industrial wind turbines continue and it is clear that ETSU-R-97 can not be relied upon to prevent sleep disturbance in those living near wind turbines. To quote Mr Peter Hadden in evidence to the House of Lords Economic Affairs Committee, printed 12th November 2008 para 6:

"There is material evidence available to show that ETSU R 97 has failed to provide a reasonable level of protection to family homes from unbearable noise pollution where wind turbines are located too close to homes. Symptoms include sleep disturbances and deprivation, sometimes so severe that families are forced to evacuate their homes in order to stabilise well-being and to resume normal family life. This is a worldwide phenomenon where wind turbines are located too close to homes."

4.2.6. It should be noted also that the application of ETSU-R-97 is advisory in PPS22, not mandatory (*should not must*). It is subordinate also to the precautionary principle set out in PPS 22. Rather than rely on a provably

inadequate set of theoretical calculations to determine setback distance, it is logical to look at the real world and the relationship between setback and noise complaints from existing sites. Human senses and opinion are used to judge visual impact. It is therefore consistent and logical to rely on human senses and opinion in respect of noise impact. Many of these sites causing problems have been in place for several years. Current applications are for large 2.0-3.0MW turbines and thus allowance must be made for their additional noise in determining setback.

4.2.7. While it may be possible to produce a reasonable acoustically based theoretical approach to calculating set-back distances (Kamperman and James 2008b), it makes more sense to rely on recommendations from observations of the effects on real people at established wind farms and the dose-response relationship described by Pedersen (2009a&b) is relevant.

4.2.8. New Zealand Standard 6808, cited in draft form above, has been published recently (March 2010). It permits a turbine noise level of 40dB $L_{A90(10min)}$ or 5dB above background, whichever is the greater. In areas where a higher degree of acoustic protection is warranted, the evening and night-time level may be set at 35dB $L_{A90(10min)}$ or 5dB above background, whichever is the greater. Wind speeds are referenced to hub height.

4.3. Conclusions

4.3.1. There are two possible approaches to judging an appropriate setback distance. The first is to determine a dose-response relationship between turbine noise and a health concern, for example, sleep disturbance. The next step is to determine an acceptable level of sleep disturbance. For example, should it be 0%, 1% or 5% of the population for 1 night per year, per month or per week? Consideration should be given to whether the measured concern, in this case reported sleep disturbance, is sufficiently sensitive. I have shown that reported sleep disturbance is the tip of an iceberg and that arousals with sleep fragmentation are likely to be more common and insidious with consequences including fatigue and elevated

blood pressure in this situation, it would be appropriate to invoke the precautionary principle and select a conservative dose level (turbine noise) that minimises the measured response (sleep disturbance). Examination of data from the Swedish and Dutch studies suggests that an external predicted noise level of no more than 35dB(A) would be appropriate. This view is supported by a presentation by members of RIVM, the widely respected Dutch National Institute for Public Health and Environment, (Jabben et al 2009) which recommends an outdoor L_{den} limit of 40dB(A) which corresponds to an external noise level of about 35dB(A). The data is now available as a RIVM report (Verheijen et al. 2009) which recommends that wind turbine parks be designed so as to stay below L_{den} 40 dB at nearby dwellings which is regarded as the "no effect" level. L_{den} 45 dB(A) is recommended as a maximum allowable limit which should avoid severe effects and minimise health effects.

Hayes (2007) notes that "the intent of New Zealand Standard 6808 is not inaudibility but the prevention of severe annoyance". The relevant section of that Standard states:

"4.4.2 Acceptable limit

As a guide to the limits of acceptability, the sound level from the WTG (or windfarm) should not exceed, at any residential site, and at any of the nominated wind speeds, the background sound level (L_{95}) by more than 5dB(A), or a level of 40 dB(A) L_{95} , whichever is the greater.

Hayes therefore concedes that the noise level above which severe annoyance occurs is 40dB(A). Thorne (2010), from an analysis of noise complaints concludes that unreasonable noise occurs at noise levels above 30dB(A) $_{LA90}$ in the presence of excess amplitude modulation. Together with van den Berg he states: "We believe annoyance and loss of amenity will be protected when the wind turbine noise limit would be 30 dBA L_{95} in conditions of low wind speed at the dwellings and modulation restricted to 3dB".

Overall, it is apparent that the present ETSU-R-97 noise limits are too high to protect receptors from severe annoyance and sleep

disturbance and that a level of 35dB(A) is appropriate, in the absence of excessive modulation.

4.3.2. The second approach is to correlate reports from those living in proximity to wind turbines to their distance to the turbines, the approach taken by, amongst others, WindVOiCe (Wind Vigilance for Ontario Communities). This has the disadvantage that symptoms are generally self-reported and subjective. Nevertheless, it can be argued that it is logical to rely on the actual reports of human receptors in the same way that human opinions are used to judge visual amenity. It has the advantage also that it may better detect those subjects that are most sensitive to turbine noise than surveys. It has the merit also of simplicity. The New South Wales Legislative Council (General Purpose Standing Committee No 5, under the Chairmanship of Mr Ian Cohen, a member of the Green Party, has recently published the report of an inquiry into rural wind farms (NSW 2009). Recommendation 7 to the NSW Planning Minister is for a minimum setback of 2 km. In the UK, Mr Peter Luff, MP for Mid-Worcestershire, introduced a Bill to Parliament to establish a legal minimum setback distance.

4.3.3. **Table II** (see end of text) shows recommendations for setback distance by a number of authorities. References can be found in the Bibliography. In general, noise engineers recommend lesser setback distances than physicians. The former rely more on measured and/or calculated sound pressures and the latter on clinical reports. It is logical to prefer the actual reports of the humans subjected to the noise rather than abstract calculations, even if the latter accurately measure ambient noise and allow for the low frequency components of wind turbine noise. Calculations can not measure annoyance and sleep disturbance, only humans can do so. In my opinion, based on the reports cited in the table and the data from the WindVOiCe survey, a minimum setback of 1.5km is appropriate.

4.35. **Turbines which result in external noise levels greater than 35dB(A) or are sited closer than 1.5km from housing therefore present an unacceptable risk of causing sleep disturbance and high levels of**

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annoyance to those residents and, to a smaller number, a risk to health.

5. Planning considerations

5.1 ETSU-R-97

5.1.1. UK Government policy is that ETSU-R-97 should be used for the assessment of the likely impact of wind turbine noise and this was restated in a 2007 policy statement. Developers will often assert that, as it is government policy, ETSU-R-97 may not be questioned. However, as Mr Justice Mitting stated in a judicial review brought by the Renewable Energy Foundation: "It will always be open to any objector to an application for permission to develop a site as a windfarm, to contend that the Statement is technically inadequate or erroneous." David Forsdick, of Landmark Chambers, a leading barrister with particular expertise in planning matters, stated, at a seminar on renewable energy on the 1st October 2008 (Forsdick 2008):

"...., general policy and guidance cannot prevent consideration of:

a. the specific facts of an individual case;

b. scientific information which suggests that the general methodology may need to be adjusted on the facts of an individual case; or

c. actual experience elsewhere on the ground which shows that the government approved methodology does not always accurately predict the impacts.

Thus, whilst it is undoubtedly true that it is not for parties to an inquiry to question the merits of government policy, their evidence on the matters in the previous paragraph is plainly capable of constituting "other material considerations" which the decision maker has to take into account and, in an appropriate case, reach a conclusion on.

5.1.2 It would seem logical that the specific facts of an individual case would include the presence of particularly sensitive or vulnerable receptors, such as the elderly and children, and the likelihood of excessive wind shear or amplitude modulation.

5.1.3. There is now a large body of scientific information showing that the ETSU-R-97 methodology is in need of adjustment for wind shear and excess amplitude modulation.

5.1.4. There is a large body of evidence also showing that ETSU-R-97 noise levels are too high for human health and well being. These include the 2009 WHO Night Noise Guidelines and the 2006 draft reports by HMP to DTI.

5.1.5. It follows that it is appropriate and reasonable for planners and decision makers not to rely exclusively on ETSU-R-97 methodology and to take account of the other material considerations set out in this paper.

6. Overall Conclusions

6.1. The appropriate mitigation of sleep disturbance and annoyance from industrial wind turbine noise is a maximum external turbine noise level of 35dB(A) or a setback of at least 1.5km.

CD Hanning

8th April 2010

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Figure 1. Sound level and annoyance for different noise sources (van den Berg 2008)

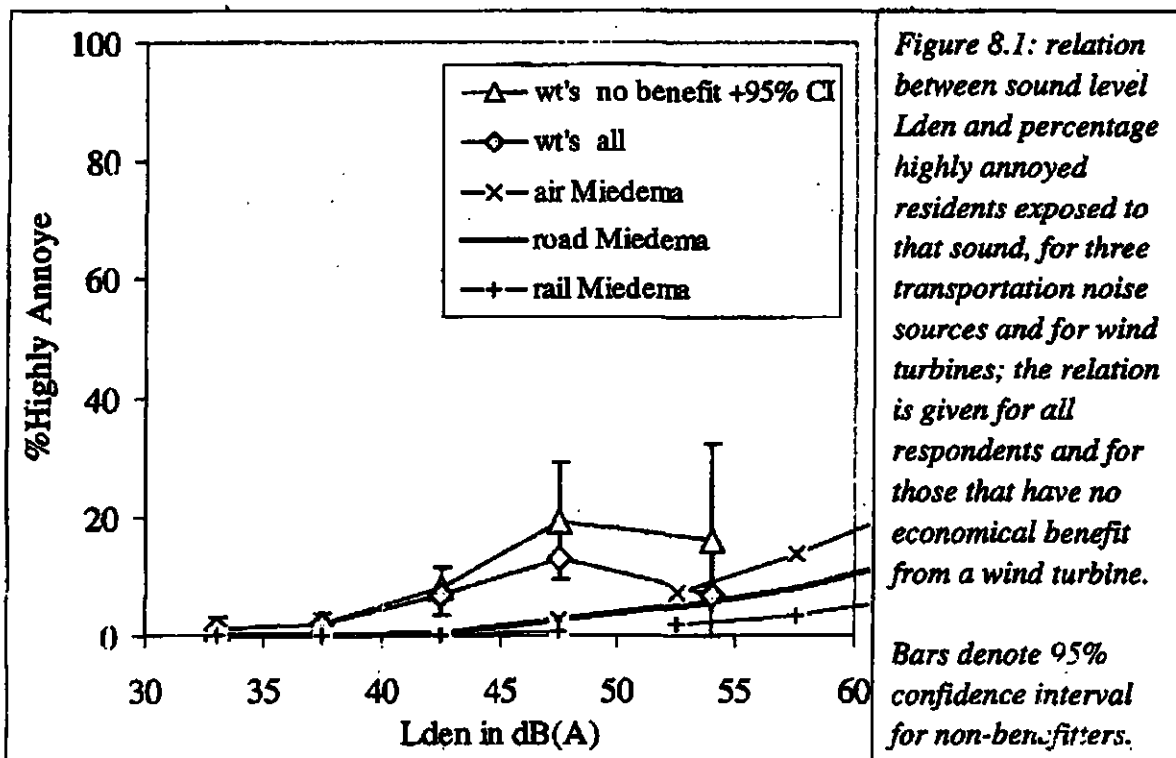
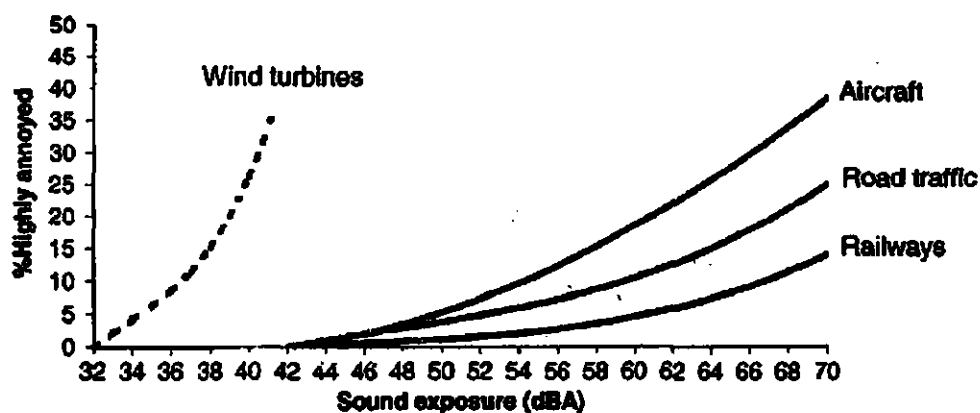


Figure 2. Sound level and annoyance for different noise sources (Pedersen E and Persson Waye, 2004)



Sound exposure is for wind turbines calculated A-weighted L_{eq} for a hypothetical time period and for transportation DNL.

Figure 3. Relationship between A-weighted sound pressure levels (equivalent levels at wind speed 8 m/s, 10 m over the ground) and proportion of respondents disturbed in the sleep by noise in three studies: SWE00 ($n = 341$), SWE05 ($n = 746$) and NL07 (only respondents that did not benefit economically from wind turbines; $n = 593$). (Pedersen 2009)

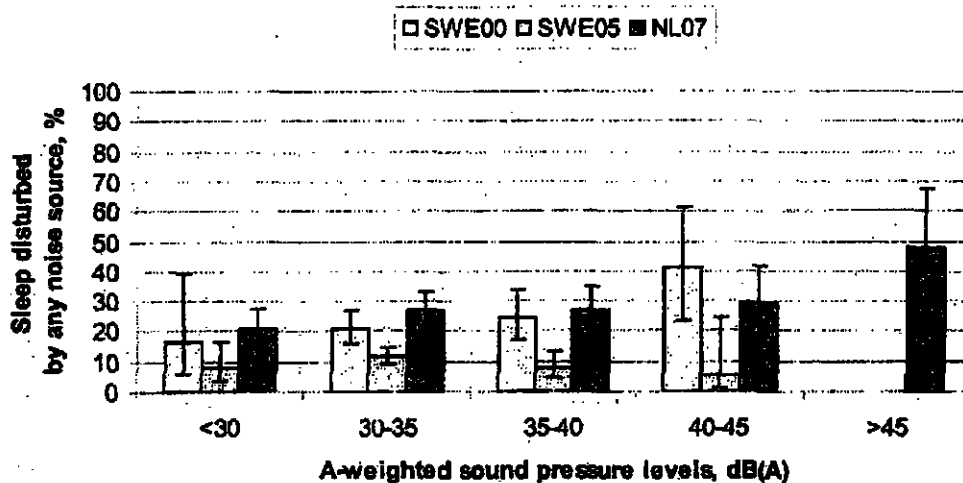


Table I. Response to wind turbine noise outdoors or indoors, proportion of respondents ($n=708$) according to 5-dB(A) sound level intervals, and 95% confidence intervals (95%CI). (From Pedersen 2009a)

	Predicted A-weighted sound pressure levels dB(A)				
	<30	30-35	35-40	40-45	>45
Outdoors n	178	213	159	93	65
Do not notice (%) (95%CI)	75 (68-81)	46(40-53)	21(16-28)	13 (8-21)	8(3-17)
Notice, but not annoyed (%) (95%CI)	20 (15-27)	36(30-43)	41(34-49)	46 (38-56)	58(46-70)
Slightly annoyed (%) (95%CI)	2 (1-6)	10(7-15)	20 (15-27)	23 (15-32)	22(13-33)
Rather annoyed (%) (95%CI)	1 (0-4)	6(4-10)	12 (8-18)	6 (3-13)	6(2-15)
Very annoyed (%) (95%CI)	1 (0-4)	1(0-4)	6 (3-10)	12 (7-20)	6(2-15)
Indoors, n	178	203	159	94	65
Do not notice (%) (95%CI)	87 (81-91)	73(67-79)	61(53-68)	37 (28-47)	46(35-58)
Notice, but not annoyed (%) (95%CI)	11(7-17)	15(11-20)	22 (16-29)	31(22-31)	38(28-51)
Slightly annoyed (%) (95%CI)	1 (0-4)	8(5-12)	9 (6-15)	16 (10-25)	9(4-19)
Rather annoyed (%) (95%CI)	0 (0-2)	3(1-6)	4 (2-8)	6 (3-13)	5(2-13)
Very annoyed (%) (95%CI)	1 (0-4)	1(0-4)	4 (2-8)	10 (5-17)	2(0-8)

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Table II. Recommendations for setback of residential properties from industrial wind turbines

Note 1. The 2km limit from edges of towns and villages seems to have been set more for visual than noise reasons

Note 2. Dixsaut and colleagues (2009) report a review of this recommendation by AFSSET. They concluded that the 1.5km setback was "not relevant" and would compromise wind park development

Authority	Year	Notes	Recommendation	
			Miles	Kilometres
Frey & Hadden	2007	Scientists. Turbines >2MW	>1.24	>2
Frey & Hadden	2007	Scientists. Turbines <2MW	1.24	2
Harry	2007	UK Physician	1.5	2.4
Pierpont	2008	US Physician	1.5	2.4
Welsh Affairs Select Committee	1994	Recommendation for smaller turbines	0.93	1.5
Scottish Executive	2007	See note 1.	1.24	2
Adams	2008	US Lawyer	1.55	2.5
Bowdler	2007	UK Noise engineer	1.24	2
French National Academy of Medicine	2006	French physicians See note 2	0.93	1.5
The Noise Association	2006	UK scientists	1	1.6
Kamperman & James	2008	US Noise engineers	>.62	>1
Kamperman	2008	US Noise engineer	>1.24	>2
Bennett	2008	NZ Scientist	>0.93	>1.5
Acoustic Ecology Institute	2009	US Noise engineers	0.93	1.5
NSW General Purpose Standing Committee	2009	Legislators	1.24	2
Thorne	2010	Aus/NZ acoustician	1.24	2